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Cooperative Agreement

Intelligent Propulsion System Foundation Technology

FINAL TECHNICAL REPORT
1 August 2003 through 30 September 2004

The Ohio State University Research Foundation
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Work Element 2.1: Intelligent Combustor
University of Dayton, Dayton, OH

Program Objectives
Fabricate a combustor incorporating advanced diagnostics and active combustor control to reduce NOx emissions by 85% relative to 1996 ICAO standards, while retaining the performance of existing commercial combustors.

Work Element 2.1: Intelligent Combustors
The University of Dayton has performing three major tasks: (1) Well-Stirred Reactor (WSR) Task, (2) Shock-Tube Task, and (3) TAPS Task. Technical work performed on these tasks will go towards meeting the objective set for the NASA Work Element 2.1: Intelligent Combustor.

2.1.1: WSR Task
WSR is a versatile laboratory research combustor that simulates the highly turbulent combustion process in a practical gas turbine combustor. UD proposed to study high-turbulence level turbulence-flame chemistry interactions processes in a high pressure (20-atm) WSR. Specifically, the WSR will provide bench-mark quality data on effects of pressure on lean blowout (LBO), NOx, and particulate emissions.

Accomplishments
UD designed, fabricated, and assembled a WSR with the following specifications:

- Operating pressure = 1-20 atm.
- Air flow rates: 2.0 lbm/sec
- Fuel flow rate: 0.2 lbm/sec
- Residence Time = 2-8 ms
- Equivalence ratio = 0.3-2.5
- Fuels: Jet A, JP-8, heptane and decane.

High-pressure WSR experiments and test results have direct practical applications in gas turbine combustor design in terms of improving combustion efficiency, combustion stability, and fuel economy and at the same time decreasing pollutant emissions. Results and conclusions of these studies will be of direct practical benefits to NASA Glenn, GEAE, Parker-Hannifin Corporation, and also the research work being performed at the Air Force Research Laboratory. Figure 1 shows a photograph of the atmospheric pressure WSR. This basic design is scaled to a 20-atm pressure design as shown in Figure 2. At present, the WSR assembly is being incorporated in the AFRL test facility.

Stouffer et al. (2005) describe the development & combustion performance of this WSR.

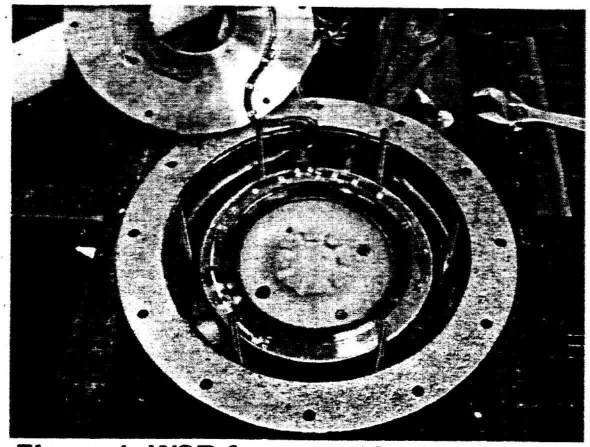
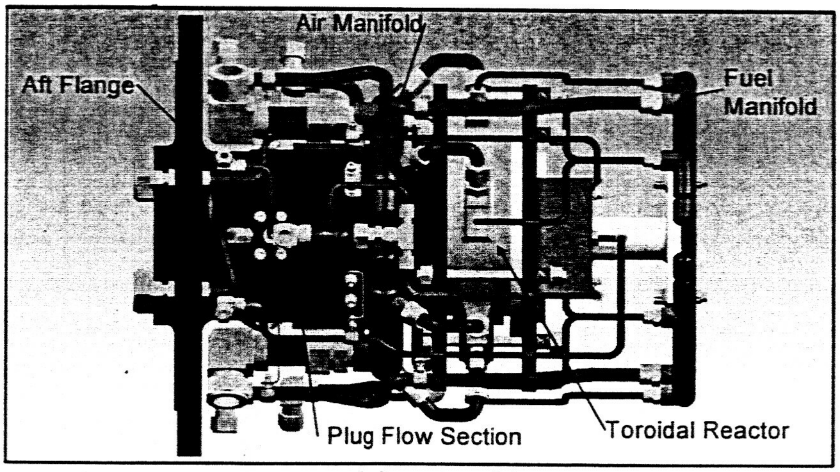
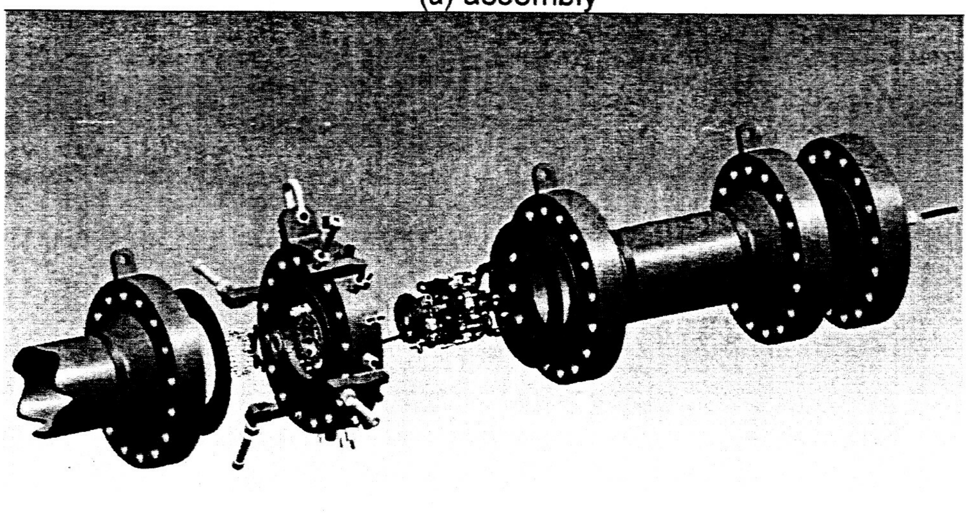


Figure 1: WSR for atmospheric pressure



(a) assembly



(b) exploded layout

Figure 2: A 20-atm WSR

2.1.2: Shock Tube Task

UD proposed to build a new 50-atm. shock tube test facility to study ignition processes, chemical kinetics, and formation of short-duration pollutant species in the ultra-high pressure, ultra-fuel lean advanced gas turbine combustors of the future. In the past, UD has expertise in using shock tubes to study the combustion characteristics of various jet fuels, alternative fuels for light duty vehicles (premixed gases), alternative diesel fuels that are being formulated to reduce particulate emission (liquid sprays), and the composite ignition delay of high performance aviation fuels (liquid sprays).

Accomplishments

UD designed, fabricated, assembled, and tested a 50—bars shock tube:

- Operating pressure = 50 atm.
- Temperature: 500-3000C
- Residence Time =0.1 to 8 ms
- Fuels: Jet A, JP-8, heptane and decane.

Figure 3 shows the assembled view of the shock tube. We initiated the high-pressure heptane combustion experiments. Figure 4 shows an example data from one of the shakedown experiments. This data was taken using 460psig helium driving 12.3psig (1380torr) argon. The calculated final temperature and pressure using an ideal gas model were 48.4atm and 1160°C, respectively. The reaction dwell time for this experiment was ~ 2ms which was measured from the moment the incident shock arrived at the end plate till the arrival of rarefaction wave.

Sidhu et al. (2005) describe the development and performance of the shock tube.

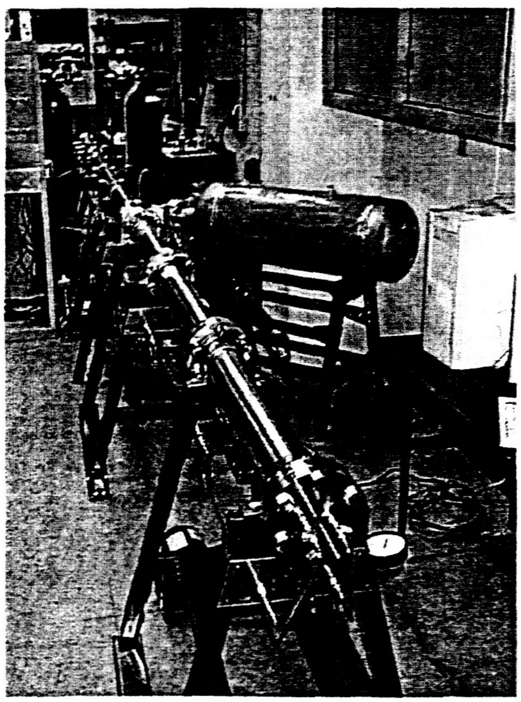


Figure 3: The UDRI high pressure, single pulse, reflected shock tube as viewed from the driver section.

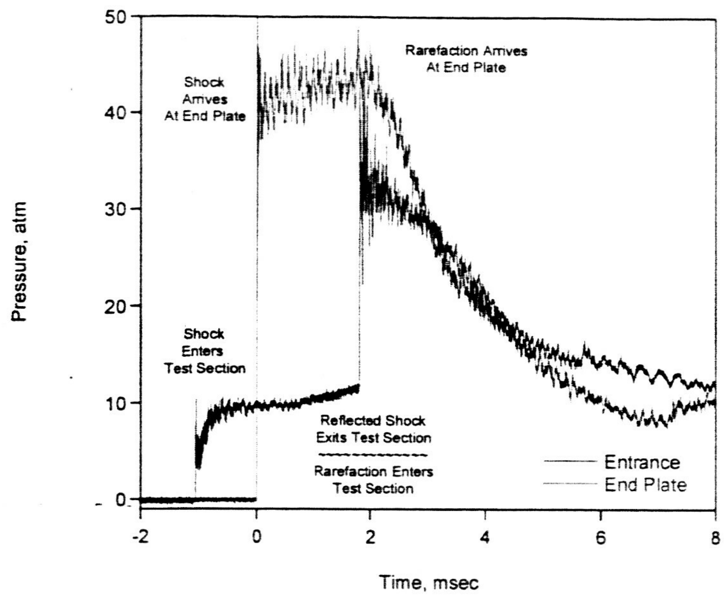


Figure 4: Example pressure traces from pressure transducers located just inside the test section and at the end plate.

2.1.3: TAPS Combustor Task

The objective of this task is to design a 20-atm. TAPS combustor test facility and adapt it to the AFRL high pressure combustor research facility. The TAPS task involves the study of turbulent fuel-air mixing, measurement of fuel concentration profiles downstream of the GEAE TAPS fuels injector, and studies of combustion processes. These tests will be performed using various fuels, and for idle and full power conditions. Such database will be used by GEAE to formulate a comprehensive mechanistic model of TAPS combustion that will be capable of predicting mixing patterns, lean blowout, and the formation of gaseous and soot pollutants.

Accomplishments

Figure 5 shows the TAPS combustor rig.

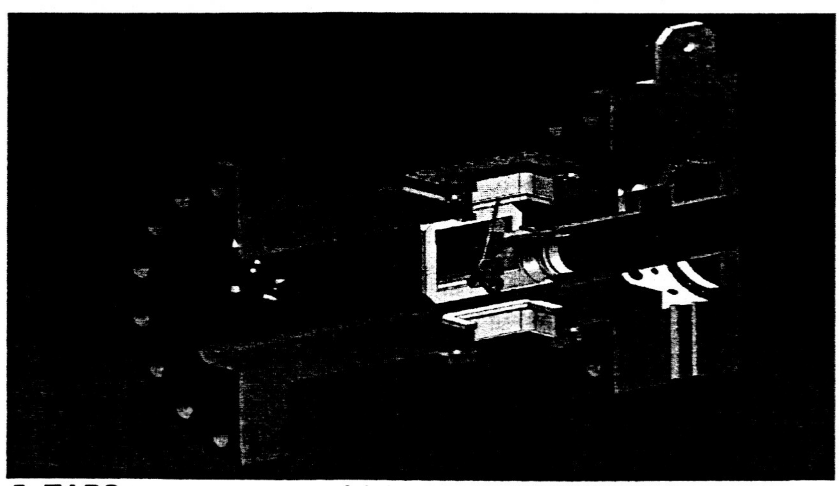


Figure 5: TAPS pressure vessel (a) quartz windows for optical access (b) TAPS combustor installed and (c) Instrumentation service flange.

The CAD design of the TAPS hardware is shown below in Figure 6. The TAPS combustor hardware fabrication is complete. The dome hardware was supplied by GE-AE and is modular to provide easy interchange of fuel injector-swirler combinations.

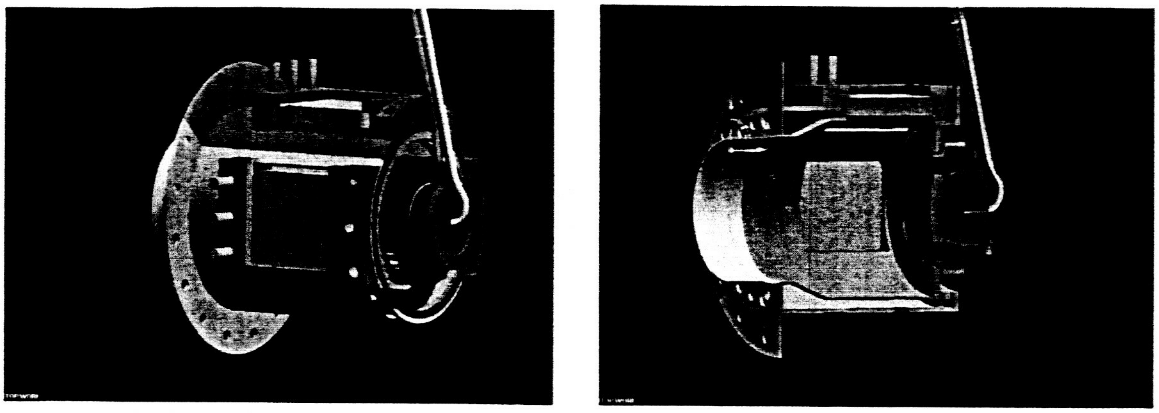


Figure 6: TAPS combustor configuration (a) quartz windows for optical access and (b) inner features of the combustor.

Summary

Work Element 2.1: Intelligent Combustors

The University of Dayton has completed all the program objectives of the work element 2.1: Intelligent Combustor. Our accomplishments include the fabrication and assembly of WSR and TAPS combustor, and testing in the 50-bars shock tube. Finally, we are preparing two AIAA papers for presentation at the forthcoming 43rd AIAA Aerospace Sciences Meeting, 10-13 January 2005, Reno, NV. These papers will provide a detailed technical documentation of our accomplishments.

References

1. S. C. Stouffer, D. R. Ballal, J. Zelina, D. T. Shouse, R. D. Hancock, and H. C. Mongia (2005), "Development and Combustion Performance of a High-Pressure WSR and TAPS Combustor," AIAA Paper No. 2005-1416, to be presented at the 43rd AIAA Aerospace Sciences Meeting, Reno, NV.

2. S. S. Sidhu, J. L. Graham, D. R. Ballal, and H. C. Mongia (2005), "Investigation of Heptane Combustion at 50-atm. Using a Shock Tube," AIAA Paper No. 2005-1447, to be presented at the 43rd AIAA Aerospace Sciences Meeting, Reno, NV.